TURBO CODES

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COMMUNICATIONS SYSTEMS ANALYSIS

It is just over a quarter century since the launch of NASA's Pioneer 9 spacecraft — the first deep-space mission that relied on error-correcting codes to enhance scientific data return.

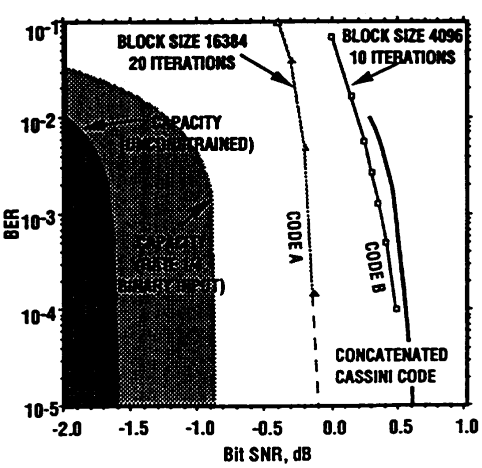
The success of that first coding system spawned a continuous sequence of improvements in channel coding. The DSN Technology Program is contributing to these advances through the efforts of the Communications Systems Analysis work area. Concatenated coding systems composed of an inner convolutional code and an outer Reed-Solomon code have been successfully used in deep space missions for over a decade. However, the decoder in the ground station is such a complex device that further improvements within this class of codes are becoming extremely expensive.

The progress in the development of new, more powerful codes has been hampered because good codes are hard to find, hard to analyze, and hard to decode. Coding theorists have traditionally attacked the problem by developing highly structured codes. This development leads to feasible decoders, although coding theory suggests that codes chosen at random should be adequate if their block size is large enough. The challenge to find practical decoders for almost-random, large codes had not been seriously considered until recently.

Just over a year ago, a new class of parallel concatenated recursive (PCR) codes, also called turbo codes, was proposed, and it was claimed that these codes had achieved near-Shannon-limit error correction performance with low decoding complexity. This claim was met with skepticism by the coding community, because several important details were omitted in the original report. However, we soon realized the potential these new codes offered the DSN and conducted an independent study to validate those claims. This effort led to the development of a new rate 1/4 PCR code with improved decoder, which requires a bit signal-to-noise ratio (SNR) of just -0.1 dB in order to achieve a bit error rate of 10^{-5} (Code A).

This compares to 0.6 dB required for that bit error rate for a concatenated code consisting of a rate 1/6 convolutional code and an outer (255, 223) Reed-Solomon code, which is the concatenated code used by Cassini. Shannon's limit, or the channel capacity, tells us that no rate 1/4 code can deliver bit error rate of 10^{-5} on a Gaussian channel with bit SNR less than -0.9 dB. But the gain of 0.7 dB over the Cassini concatenated code is not the only important gain from this code. Decoding complexity is so much smaller that it is possible to consider whether decoding in software is possible at deep space data rates.

Recent tests on JPL's T3D Cray computer using a PCR code (Code B) with performance similar to the Cassini code delivered a decoding speed of 450 kb/s, which exceeds Cassini's requirement of 250 kb/s. We continue to consider whether decoding in software is practical, as we look for the best PCR code for the DSN. This fits the DSN Technology Program's goal of using new technology to cut costs in digital signal processing operations while maintaining or increasing performance.



spheric effects, lower receive antenna efficiency, and higher receiver noise temperature. The DSN Technology Program has been developing Ka-band technologies and operational concepts to pave the way for eventual adoption of Ka-band for deep-space missions. With planned development, Ka-band is expected to have a 6 dB, or factor of four, advantage by the turn of the century.

Pluto Fast Flyby is a mission that can benefit from Ka-band technology. The spacecraft will, after a long cruise, generate 1 to 2 Gbits of data during Pluto Flyby. The data will be stored in an on-board solid-state recorder for later transmission to Earth. The current telecom design provides both X-band and Ka-band downlink capability. Major telecom hardware includes a 2-m dual frequency high-gain antenna, 5-W X-band solid-state power amplifier (SSPA), and 2.7-W Ka-band SSPA. Using these design parameters, analyses indicate that Ka-band would have a significantly higher data rate than X-band for the same receive antenna size. For example, at 30 degrees elevation and 90% weather margin, Ka-band data rate using a 34-m BWG antenna in Goldstone is 4 dB higher than that for X-band using a 34-m HEF antenna, which is the best operational X-band antenna. (It should be noted that the current Pluto Flyby telecom design maximizes X-band performance. Otherwise, Ka-band advantage could be even greater. Based on recent Ka-band antenna efficiency measurements, Ka-band would have about a 7.5-dB advantage over X-band, assuming equal spacecraft performance.) At lower elevation angles, the Ka-band data rate advantage decreases because of increased atmospheric effects and gravity-induced deformation of the 34-m BWG antenna. Despite the reduced performance at low elevation angles, the data volume per pass for Ka-band is still higher than that for X-band by 3 dB (a factor of 2), based on a recent study which assumes a fixed data rate (i.e., no data rate switching during the entire pass), and a maser low-noise amplifier, listen-only path for both Ka-band and X-band. With 3-dB advantage, Ka-band can benefit Pluto Fast Flyby by reducing the playback time (and hence mission operations costs) needed to retrieve the recorded data from the spacecraft.

Editor's note: Since this article was written, a new mission to Pluto, Pluto Express, has been developed. Studies are under way to establish the telecom baseline, and to further reduce costs for Pluto Express.

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